



**WALLACE H. COULTER SCHOOL OF ENGINEERING**  
*Technology Serving Humanity*

**MEMORANDUM**

From: Bill Jemison  
To: Dr. Daniel Tam, ONR  
Date: 4/12/2011

Subject: Progress Report 002– Chaotic LIDAR for Naval Applications (1/1/2011– 3/31/11)

This document provides a progress report on the project “Chaotic LIDAR for Naval Applications” covering the period of 1/1/2011– 3/31/11.

**Chaotic LIDAR Source Development:**

- Studies have ruled out using open optical resonators due to coupling challenges and the need for custom optical coatings.
- Fiber ring lasers were investigated. The investigations showed that fiber ring lasers are capable of high power, and it is relatively easy to build. Commercially available continuous wave (CW) green fiber lasers are available at the 5-10W levels. A CW laser operating at 542.8nm has been successfully demonstrated by Yamashita, Qin, Suzuki, and Ohishi using Tb3+-doped fluoride fiber, and simulation tools for designing fiber ring laser exist.
- Other options for obtaining fiber lasing in the blue-green are currently being evaluated including up-conversion via pumping by a 970nm diode laser based on work by Weichmann, Baier, Heusler, and Moench.

**LIDAR System Studies and Experimental Design:**

- A proof-of-concept fiber ring laser shown in Figure 1. was constructed using existing components at the commercial telecommunications wavelength of 1.55um. Figure 2 shows that the laser is capable of lasing in multiple modes simultaneously and that the temporal output is noise-like. However, the autocorrelation of the signal shows a well-defined autocorrelation peak of the type desired from the Chaotic LIDAR source.
- Theory and computer programs necessary to design the planned system-level experiments are in progress.
- Equipment was specified and is in the process of being finalized and ordered and experimentation is planned between May to August 2011.

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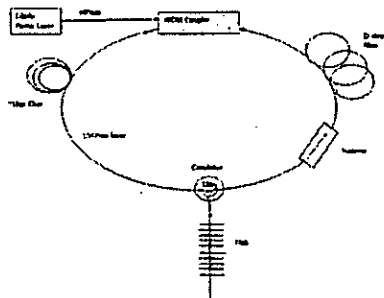


Figure 1. Proof-of-concept fiber ring laser experiment performed at 1.55  $\mu\text{m}$ .

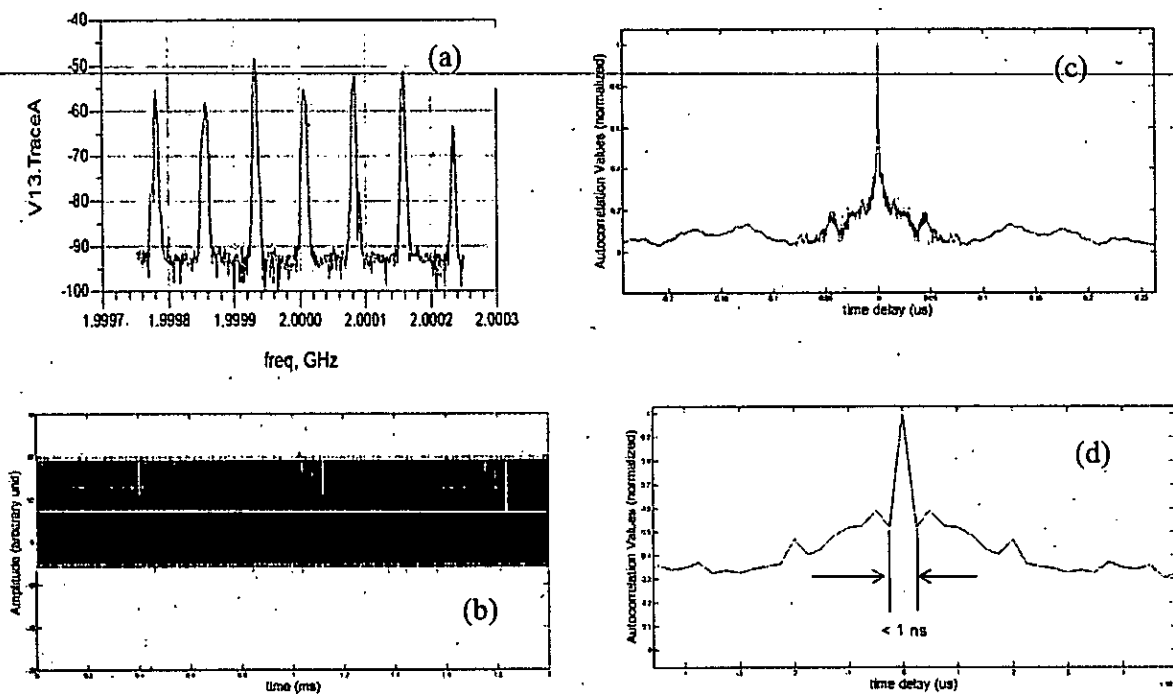


Figure 2. (a) shows simultaneous lasing of multiple modes in the fiber ring laser which produce the noise-like temporal output of (b). The autocorrelation of (b) shows a strong autocorrelation peak in (c) which is examined in more detail in (d)

1. **FY2011 Budget Summary and Plan** - Clarkson submitted an invoice of \$26,284 to ONR on 3/29/2011 for the second quarter (Q2) of FY2011 and the budget was discussed with the ONR program manager in a memorandum dated 3/29/2011.

**Memorandum**

**From:** Bill Jemison, Clarkson University

**To:** Dr. Daniel Tam

**Date:** February 10<sup>th</sup>, 2011

**Subject:** Progress Report 001– Chaotic LIDAR for Naval Applications (7/01/10 – 12/31/10)

This document provides a progress report on the project “Chaotic LIDAR for Naval Applications” covering the period of 7/01/10 to 12/31/10.

cc. Dr. Linda Mullen

## Progress Report 001– Chaotic LIDAR for Naval Applications (7/01/10 – 12/31/10)

The primary activity associated with this period was related to contractual matters. The PI did not receive authorization to begin working on the project from the Clarkson Division of Research until November 11<sup>th</sup>, 2010 and there were no charges incurred during this period. Nevertheless, we would like to report the following activities that were accomplished.

**Technical Approach-** Several approaches were outlined in the project proposal for the generation of chaotic lidar signals. At the time the proposal was written, the use of open optical resonators (OORs) seemed promising. OORs could theoretically support many simultaneous longitudinal modes necessary for chaotic signal generation. We developed a simulation to allow us to design OORs to support high order modes such as the “M” mode shown in Figure 1 as a first step to the chaotic OOR. The simulation allowed us to determine the excitation conditions (e.g. the angle and lateral offset necessary for a given mode with a specified set of mirrors and cavity length). For example, the “M” mode is a stable mode that traces a path in the resonator that includes two distinct reflection points on one of the resonator mirrors and three distinct reflection points on the other resonator mirror. The upper plot in Figure 1 shows the ray trajectory of a cavity designed for the “M” mode. The photograph shown in Figure 1 shows the two reflection points on the left resonator mirror.

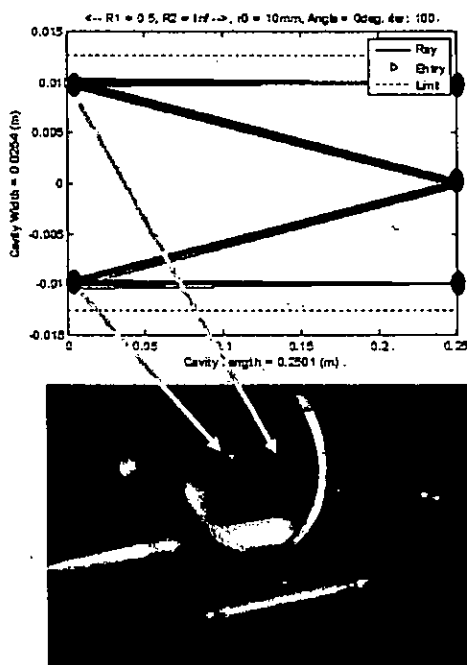


Figure 1. Initial experiments on Open Optical Resonators. Generation of a stable higher order “M” mode is shown.

There are two drawbacks to this approach. The first is that custom optics is required to minimize coupling losses into and out of the resonator. We were not able to find commercial off-the-shelf (COTS)

components for the OORs that we wished to design. High losses would preclude the generation of optical power levels necessary for system-level experiments. Second, the OORs required precise positioning accuracies and expensive kinematic positioners which are also not desirable for the system-level experiments that are planned.

Therefore, we reexamined some of the other approaches to optical generation of chaos. Currently, we believe that a fiber laser approach is extremely promising. Fiber lasers are a mature technology and commercially available products are available at 532nm as well as in the 1100-1700 nm range. Output powers are available in the 0.5W to 30W range which are compatible with system-level experiments. Further, experimental fiber lasers are relatively easy to build. Several companies sell the doped fiber and at least two companies offer fiber laser simulation software. The dynamic properties of fiber lasers have been simulated and wideband chaotic behavior has been predicted [1]

We put together a fiber ring laser at 1550 nm as a proof-of-concept experiment. A picture of the laser and plots of the optical and microwave spectrum are shown in figure 2. Oscillation at multiple microwave frequencies was observed, but chaotic behavior was not in this initial experiment. However, this was only the initial experiment and we will be reporting additional results that are promising in the next progress report.

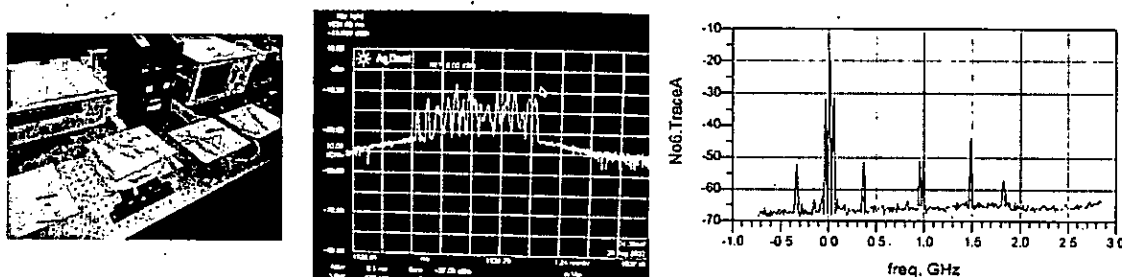


Figure 2. Proof-of-concept fiber laser - The left plot is the optical spectrum. The right plot is the microwave spectrum. Oscillation at multiple microwave frequencies was observed, but chaotic behavior was not in this initial experiment. The approach shows promise, however.

We are currently investigating the capabilities of two fiber laser simulation programs to assist us with our fiber laser design.

[1] H.D.I. Abarbanel, et. al. "Chaotic dynamics in erbium-doped fiber ring lasers," Physical Review A, Vol. 60, No. 3, Sept, 1999, pp. 2360-2374.

**Staffing** – Significant progress was made regarding staffing this project. The PI started working at Clarkson University in July of 2010 and it took more time than anticipated to attract top students to the project. We are happy to report, however, that three students are currently taking a directed study course with William Jemison in the area of lidar technology. Two will work on this project and one will work on a related pending ULI project. All three students are US citizens. Dennis Perez is finishing his

master's degree in physics and will begin his Ph.D. this summer under a separate pending ULI program. Reed Hollinger is currently finishing his bachelor's degree at Clarkson. Reed is a double major in electrical engineering (GPA= 3.67) and physics (4.0) Reed will begin his graduate work at Clarkson this summer working on this project. He has applied to the NREIP program and plans to pursue the Ph.D. Scott Carl is a junior undergraduate who is also a double major in electrical engineering and physics who is interested in graduate school. Mr. Hollinger and Mr. Carl will continue to work on this project. Dr. Jemison has also started working with Dr. Li who is serving as a technical consultant on the project as described in the proposal.

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